

TRI-CRYSTAL FIXED EXIT MONOCHROMATOR

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It is proposed a novel design of an X-ray monochromator which uses three crystals marked with A, B, C on the figure 1a. The exit beam, CD , turns in horizontal plane on the angle 2α with respect to the incoming beam, SA (and the segment AC bisects this angle, see the fig. 1a). So, this kind of monochromator is well suitable for side beam-lines; several tunable beam-lines can be built for a one fan beam of synchrotron radiation (from wiggler or bending magnet).

The first and the last crystals are equal (of the same interplanar spacing d), and fixed, while the second one is moving in the middle plane ($|AB| = |BC|$) and has about half spacing, $d^* \approx d/2$. The next sets of crystals are well appropriate:

$$\text{Si-111, Si-311, Si-111, in this case } k^2 = (d^*/d)^2 = 3/11;$$

$$2 \times \text{Si-220} + \text{Si-440}, \quad k^2 = 0.25;$$

$$2 \times \text{Si-311} + \text{Si-533 (or Si-444)}, \quad k^2 = 11/43 \text{ (or } 11/48).$$

The tilt from vertical, angle φ , and the length $h = |OB|$ define completely the second crystal's position. It is convenient to take the unit of length as follows:

$$|AO| = |AC|/2 = 1;$$

this unit can be as small as the crystal's sizes, that is about 4–5 cm.

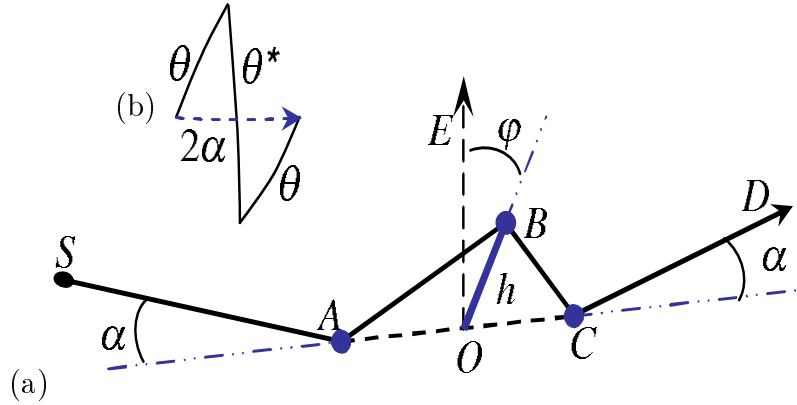


Figure 1. The scheme of tri-crystal monochromator (a); Bragg angles of the crystals, θ, θ^* , and the resulting turn of outgoing beam, $\alpha = \text{const}$ (b).

Taking the point O as the center of Cartesian coordinate system (axis 3 is vertical, along \overrightarrow{OE} ; axis 1 goes along \overrightarrow{AC}), one can write the crystals' coordinates:

$$A = (-1, 0, 0), \quad C = (1, 0, 0), \quad B = (0, -h \sin \varphi, h \cos \varphi).$$

Then, the unit vectors along the beam after the first and the second reflection, \vec{n}_1 and \vec{n}_2 , look as follows:

$$\vec{n}_1 = \frac{(1, -h \sin \varphi, h \cos \varphi)}{\sqrt{1+h^2}} \propto \overrightarrow{AB}, \quad \vec{n}_2 = \frac{(1, h \sin \varphi, -h \cos \varphi)}{\sqrt{1+h^2}} \propto \overrightarrow{BC},$$

while the unit vectors along incoming and outgoing beams read:

$$\vec{n}_{\text{in}} = (\cos \alpha, -\sin \alpha, 0), \quad \vec{n}_{\text{out}} = (\cos \alpha, \sin \alpha, 0),$$

The Bragg angles of crystals, θ and θ^* (the odd crystals have the same Bragg angle, θ , because of symmetry – mirror plane permutes A and C) can be find straightforwardly:

$$\cos 2\theta = (\vec{n}_{\text{in}} \cdot \vec{n}_1) = \frac{\cos \alpha + h \sin \varphi \sin \alpha}{\sqrt{1+h^2}}, \quad (1)$$

$$\cos 2\theta^* = (\vec{n}_1 \cdot \vec{n}_2) = \frac{1-h^2}{1+h^2} = 1 - 2\sin^2 \theta^*, \quad (2)$$

These angles should be (energy) related by means of the next requirement:

$$d \sin \theta = d^* \sin \theta^*, \quad \text{or } k = \frac{d^*}{d} = \frac{\sin \theta}{\sin \theta^*}. \quad (3)$$

The figures 2 and 3 shows h and φ as functions of the Bragg angle θ for two choices of k ; these functions follow from Eqs. (1)–(3) and read as follows:

$$h = \frac{\sin \theta}{\sqrt{k^2 - \sin^2 \theta}}, \quad \sin \varphi = \frac{\sqrt{1+h^2} \cos 2\theta - \cos \alpha}{h \sin \alpha}. \quad (4)$$

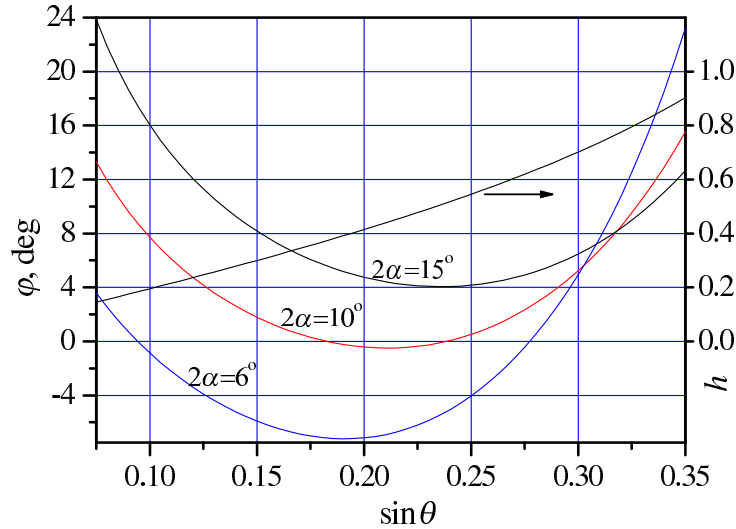


Figure 2. The plot $h(\sin \theta)$, and the curves $\varphi(\sin \theta; \alpha)$ for different α ; $k^2 = 3/11$.

It is obvious that very small travel of the second crystal, 1–2 cm, suffices for doubling $\sin \theta$ (and energy of the exit beam); so, one can use very small stage driven by piezo motor. A usual double crystal fixed exit monochromator needs much more lengthy positioner, see e.g. [1].

The tilt from vertical of the reflection plane of the odd crystals, the angle ψ , also can be find from considering the height of the point B :

$$H = h \cos \varphi = \sqrt{1 + h^2} \sin 2\theta \cos \psi, \quad \cos \psi = \frac{\cos \varphi}{2k \cos \theta}.$$

The more robust expression gives also the sign of this angle (the positive direction is chosen inward, i.e. toward the letter E):

$$\sin \psi = \frac{\sin \alpha - h \sin \varphi \cos \alpha}{2kh \cos \theta}.$$

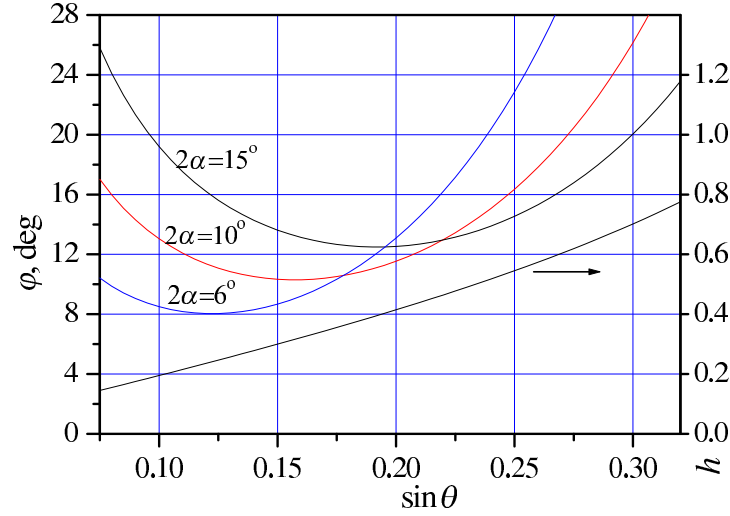


Figure 3. The plot $h(\sin \theta)$, and the curves $\varphi(\sin \theta; \alpha)$ for different α ; $k^2 = 0.25$.

In contrast to the double-crystal scheme of general position considered in [2] (which also suitable for side beam-lines), the new variant does not lead to a tilt of exit beam profile (and its polarization): it is clear from fig. 1b that two spherical triangles formed by arcs $\alpha^{-1}, \theta, \theta^*, \theta$ cancel one another (they are path-traced in opposite directions).

One may think also about bent crystals as a way to focus the exit beam; this option is especially important for hard X-ray range where grazing mirrors do not work.

[1] N. Gavrilov, I. Zhogin, A. Shmakov et al., "Lay-out of ultrahigh-vacuum DC-monochromator", SRI-03 proc., ed. by T. Warwick et al. AIP Conf. Proc., V.705. Melville, NY-2004, 691–694.

[2] N. Gavrilov, I. Zhogin, M. Sheromov, B. Tolochko, Nucl. Instr. and Meth., **A543** (2005) 375–380; arXiv.org/physics/0306191.